A DUAL MICROWAVE AND OPTICAL OSCILLATOR

X. Steve Yao and Lute Maleki

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr., Pasadena, CA 91109
Tel: 818-393-9031, Fax: 818-393-6773
Email: xsyao@horology.jpl. nasa.gov

ABSTRACT

We [redacted]nd [redacted]novel [redacted] which a microwave oscillation is generated and is directly coupled with an optical oscillation, and vise versa. With the mutual influence between the microwave and the optical oscillations, this device is capable of generating short stable optical pulses (subpicosecond) and spectrally pure microwave signals at frequencies greater than 50 GHz simultaneously.

A DUAL MICROWAVE AND OPTICAL OSCILLATOR

Generating high spectral purity and high stability microwave and millimeter wave signals are of paramount significance in microwave photonic communication, mobile communication, and radar systems. The opto-electronic oscillator[1,2] (OEO) is attractive for such an application due to its superior properties of high spectral purity, high frequency generation capability, tunability, dual electrical and optical interfacing capability, and dual optical and electrical output capability.

In a separate front, stable mode locked lasers for generating short optical pulses are extremely important for numerous applications, including fiber optical communications, material research, spectroscopy, nonlinear optics, remote sensing, medicine, and so on. However, due to laser cavity fluctuations, making a stable mode-locked laser generally involves complicated electronic setups[3,4].

In this paper, we report a novel device called Coupled Opto-Electronic Oscillator (COEO) which readily accomplishes the two seemingly unrelated functions simultaneously: it acts both as a microwave source and a stable source of short optical pulses at the same time. Due to the mutual stabilization effect of the microwave and optical signals, no electronics is required to maintain the device at an optimum operation point.

Device Description

The Basis of the COEO is similar to OEO in that light from a laser source is used in an electro-optic feedback loop to generate a microwave oscillation. However, unlike the OEO, here the microwave oscillation is fed back to the spacing much smaller than the mode spacing of the ring laser, as shown in Fig. 2b and 2d. The center frequency of the RF bandpass filter is chosen such that it is equal to an RF beat frequency of different modes of the ring laser, as shown in Fig. 2c. The bandwidth of the filter is chosen to be narrower than the spacing of the beat frequencies (equivalent to the mode spacing of the ring laser). Within the pass band, there are many OEO modes competing to oscillate. However, the winner is the mode with a frequency closest to a beat frequency of the laser's longitudinal modes, since only this OEO mode can get energy from the laser, as shown in Fig. 2d. This OEO mode is fed back to modulate the gain of the ring laser and effectively mode locks the ring laser. The mode locking causes the mode spacing of the mode-locked laser be equal to the frequency of the oscillating OEO mode, which is a multiple of the natural mode spacing of the laser, as shown in Fig. 2e. Because all the oscillating modes in the mode-locked laser are forced in phase, all the mode beat signals between any two neighboring laser modes will add up in phase and generate a strong signal at the frequency of the oscillating OEO mode. This enhanced mode beat signal in turn provides more gain to the oscillating OEO mode and reinforces its oscillation, as shown in Fig, 2f.

This is effectively a double loop OEO described previously,[5] except that here the second loop is a pure optical cavity and is an integral part of the pump laser. However, from the outside it is just like a single loop OEO without any extra components. Because the optical cavity can be made very short, a laser mode spacing can be made much larger than possible with an opto-electronic loop. The larger mode spacing ensures a large frequency tunability of the COEO and may result in the elimination of the bulky RF filter used in an ordinary OEO.

Experimental Results

In the first experiment, a bandpass filter centered at 300 MHz with a bandwidth of 13 MHz was used in the opto-electronic loop. The mode beat spectrum of the mode locked laser is shown in Fig. 3a. It was measured at the optical output port of the COEO using a photodetector with a bandwidth of 18 GHz, and a HP 8562A spectrum analyzer. The peaks of the RF spectrum results from the beat between the longitudinal modes in the ring laser. The lowest frequency corresponds to the beat between any two neighboring modes and the second lowest frequency corresponds to the beat between every other modes, and so on. It can be inferred from the spectrum that about 20 modes of the ring laser were mode locked. Fig. 3b shows the RF spectrum of the oscillation signal measured at the RF output port. A clean signal at 288 MHz with a power of -30 dBm is evident. Taking the -35 dB coupling ratio of the RF coupler into account, the RF signal circulating in the loop is about 5 dBm, which is limited by the RF amplifier used. The ring laser, as expected, was also automatically mode locked by this self-generated RF signal to produce a train of short optical pulses, as shown in Fig. 3c. The pulse width is about 250 ps while the periodicity of the pulses is about 3.6 ns. The time domain data were taken with a HP CSA803 communication signal analyzer.

In another experiment, a filter centered at 800 MHz with a bandwidth of 40 MHz was used to replace the 300 MHz filter. Now the COEO oscillates at about 800 MHz and the oscillating RF signal mode locks the ring laser. The RF spectrum of the COEO is shown in Fig. 4a. It is evident from the figure that a signal with a high spectral purity was obtained with the COEO. The corresponding pulse train of the mode locked ring laser is shown in Fig. 4b. It can be seen that the pulse width is about 50 ps and the period of the pulse train is about 1.2 ns. As expected, the pulse width is greatly shortened with the increase of the oscillation frequency. While much shorter shorter pulses can be obtained with increased COEO oscillation frequency, we were unfortunately limited by the slow response of the SOA resulting from non-optimized packaging. We anticipate that by directly using a multimode diode laser with a simple FP cavity a very compact and efficient COEO can be constructed to generate a stable high frequency (>50 GHz) RF oscillation and a train of stable, high repetition rate, and subpicosecond optical pulses simultaneously.

Note that due to a self-correcting mechanisms of the coupled oscillation, the mode locked laser output and the microwave output were both very stable. The detailed description of the phase relationship of the optical and microwave signals of the coupled oscillation will be discussed in a separate paper. As in an ordinary OEO, we expect further improved stability and spectral purity of the opto-electronic oscillation with increased opto-electronic loop length (few km), which will in turn make the laser pulses more stable.

It should be noticed that the technique of the regenerative mode locking[6,7] somewhat resembles COEO. However, unlike a COEO, in the regenerative mode-locking setup the opto-electrical feedback loop does not oscillate and the stability of the laser and the mode beat signal are completely determined by the laser cavity. On the other hand, in a COEO, the opto-electronic loop is required to oscillate and the modes in the opto-electrical oscillator is coupled with the laser modes. Consequently the stability of the OEO oscillation will influence the laser oscillation and vise versa.

In summary, we demonstrated a Coupled Opto-Electronic Oscillator (COEO) in which the laser oscillation is directly coupled with the electronic oscillation. Such a coupled oscillator easily accomplishes single mode selection even with a very long opto-electronic feedback loop, a task which is difficult to accomplish in an ordinary OEO. In addition, in a COEO a multimode laser is used to pump the electronic oscillation. The coupling of the microwave oscillation with the laser causes the laser to modelock, generating stable optical pulses and microwave signals simultaneously. We anticipate the concept of the COEO can be applied to any type of laser systems, including Er^{+} doped fiber laser, solid state laser, diode laser, and gas laser systems to generate stable optical pulses down to subpicoseconds.

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration, We thank G. Lutes and J. Dick for helpful discussions.

REFERENCES

1. X. S. Yao and L. Maleki, "Optoelectronic microwave oscillator," J. Opt. Sot, Am. B, Vol. 13 (8), pp 1725-1735 (1996).

2, X. S. Yao and L. Maleki, "Optoelectronic microwave oscillator for photonic systems," IEEE J. Quantum Eletron. Vol. 32 (7), pp1141-1149 (1996).

3. T. Kinsel, "A stabilized Mode-locked Nd:YAlG laser using electronic feedback," IEEE J. Quantum. Electron., Vol. QE-9 (l), pp. 3-8 (1973).

4. J. B. Georges, L. Buckman, D. Vassilovski, J. Park, M. H. Kiang, O. Solgaard, and K. L. Lau, "Stable picosecond pulse generation at 46GHz by modelocking of a semiconductor laser operating in an optoelectronic phaselocked loop," Electron. Lett., Vol. 30 (l), pp. 69-71 (1994).

5. X. Steve Yao and Lute Maleki, "Opto-electronic oscillator and its applications," SPIE Proceedings, Vol. 3038, pp.97-107 (1997).

6. G. R. Huggett, "Mode-locking of CW lasers by regenerative RF feedback," Appl. Phys. Lett., Vol. 13 (5), pp. 86-87 (1968).

7. M. Nakazawa, E. Yoshida, and Y. Kimura, "Ultrastable harmonically and regeneratively modelocked polarization-maintaining erbium fiber laser," Electron, Lett., Vol. 30 (19), pp. 1603-1605 (1994).

FIGURE CAPTIONS

Fig.1 a) The ring laser built with a semiconductor optical amplifier. b) The measured power vs. drive current curve of the ring laser.

Fig. 2 a) The schematic of a coupled opto-electronic oscillator. b) All possible laser modes with a mode spacing of $\Delta\upsilon$. They have random phases in the absence of the electro-optic feedback, c) All possible mode beat frequencies of the laser modes in the photodetector. The lowest frequency ($\Delta\upsilon$) corresponds to the sum of the beats between adjacent modes, the second lowest frequency ($2\Delta\upsilon$) corresponds to the sum of the beats between-every other modes, and so on. Due to the random phases of the laser modes, these beat signals are weak and noisy, d) All possible oscillating modes defined by the opto-electronic loop. Only those modes aligned with a mode beat frequency can get gain (or energy) from the laser. An electrical filter with a bandwidth narrower than the mode spacing of the laser selects one OEO mode (f= $3\Delta\upsilon$ in the illustration) to oscillate. e) The selected OEO oscillation then drives and mode-locks the laser, limiting the number of oscillating laser modes and forcing them to oscillate in phase. f) The beat of the in-phase laser modes in turn greatly enhances the selected OEO oscillation.

Fig. 3 COEO with 300 MHZ filter, a) Mode beat spectrum of the COEO measured at the optical output port. b) The RF spectrum of the COEO measured at the electrical output port. c) The time domain measurement of the COEO at the optical output port.

Fig. 4 COEO with 800 MHZ filter. a) The RF spectrum of the COEO at RF output port. The laser is driven at a current of 102.67 mA and span and the resolution bandwidth of the measurement are 10 kHz and 100 Hz respectively. b) The time domain measurement of the COEO at the optical output port. A train of 50 ps short pulses is evident.

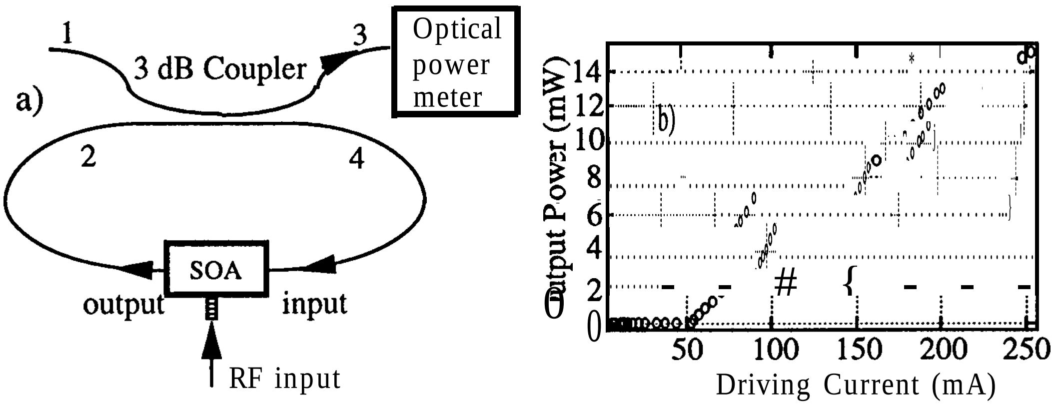

Fig. 1

Yao & Maleki, “Coupled Opto-electronic Oscillator”

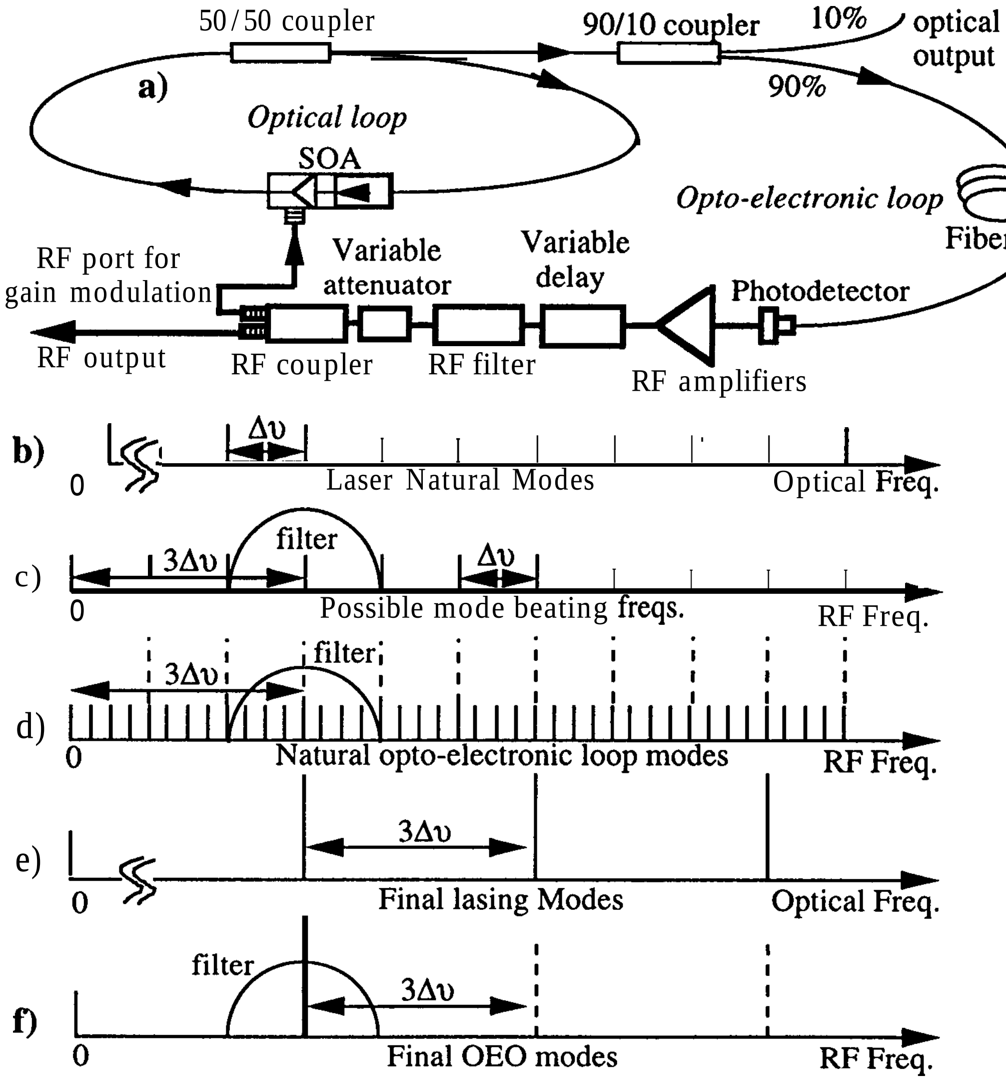

Fig. 2

Yao & Maleki, "Coupled Opto-electronic Oscillator"

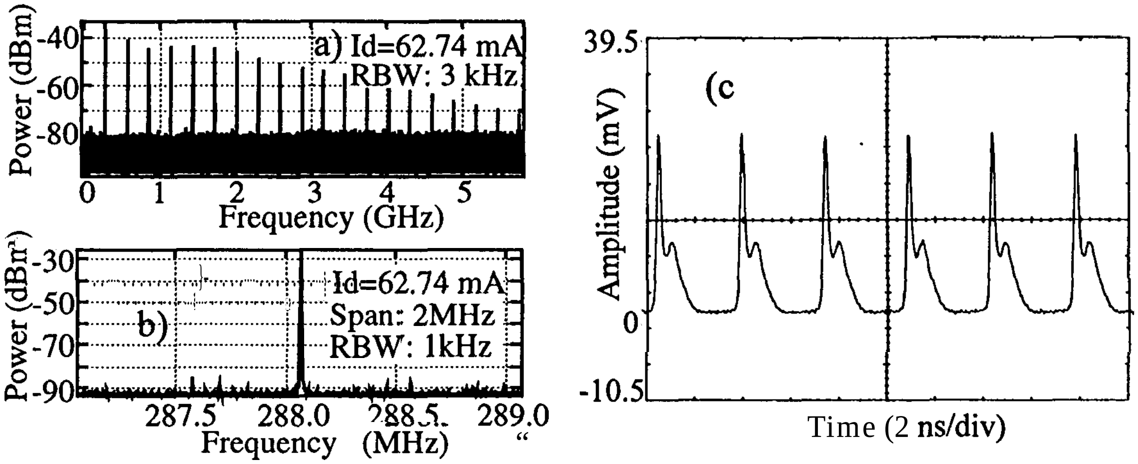

Fig. 3

Yao & Maleki, "Coupled Opto-electronic Oscillator"

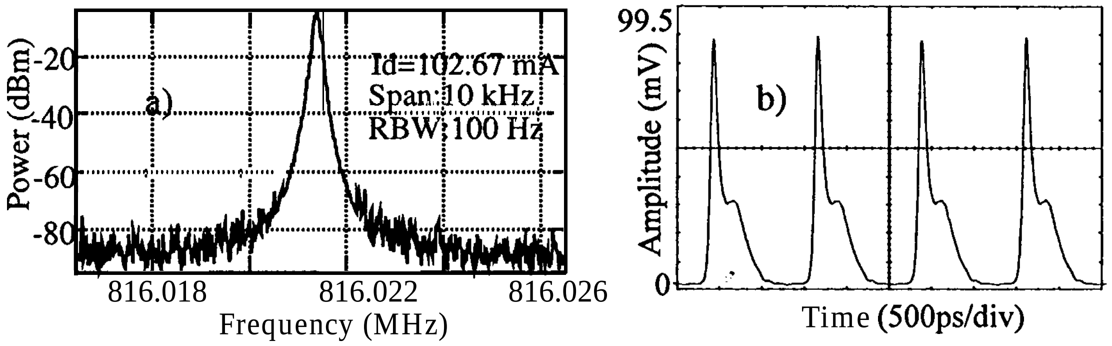

Fig. 4

Yao & Maleki, "Coupled Opto-electronic Oscillator"